

In cooperation with the City of Austin

Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) and Major and Trace Elements in Simulated Rainfall Runoff From Parking Lots, Austin, Texas, 2003

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By Barbara J. Mahler, Peter C. Van Metre, and Jennifer T. Wilson

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**U.S. Department of the Interior
U.S. Geological Survey**

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Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) and Major and Trace Elements in Simulated Rainfall Runoff From Parking Lots, Austin, Texas, 2003

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Abstract

Samples of creek bed sediment collected near seal-coated parking lots in Austin, Texas, by the City of Austin during 2001–02 had unusually elevated concentrations of polycyclic aromatic hydrocarbons (PAHs). To investigate the possibility that PAHs from seal-coated parking lots might be transported to urban creeks, the U.S. Geological Survey, in cooperation with the City of Austin, sampled runoff and scrapings from four test plots and 13 urban parking lots. The surfaces sampled comprise coal-tar-emulsion-sealed, asphalt-emulsion-sealed, unsealed asphalt, and unsealed concrete. Particulates and filtered water in runoff and surface scrapings were analyzed for PAHs. In addition, particulates in runoff were analyzed for major and trace elements. Samples of all three media from coal-tar-sealed parking lots had concentrations of PAHs higher than those from any other types of surface. The average total PAH concentrations in particulates in runoff from parking lots in use were 3,500,000, 620,000, and 54,000 micrograms per kilogram from coal-tar-sealed, asphalt-sealed, and unsealed (asphalt and concrete combined) lots, respectively. The probable effect concentration sediment quality guideline is 22,800 micrograms per kilogram. The average total PAH (sum of detected PAHs) concentration in filtered water from parking lots in use was 8.6 micrograms per liter for coal-tar-sealed lots; the one sample analyzed from an asphalt-sealed lot had a concentration of 5.1 micrograms per liter and the one sample analyzed from an unsealed asphalt lot was 0.24 microgram per liter. The average total PAH concentration in scrapings was 23,000,000, 820,000, and 14,000 micrograms per kilogram from coal-tar-sealed, asphalt-sealed, and unsealed asphalt lots, respectively. Concentrations were similar for runoff and scrapings from the test plots. Concentrations of lead and zinc in particulates in runoff frequently exceeded the probable effect concentrations, but trace element concentrations showed no consistent variation with parking lot surface type.

Introduction

Contamination of aquatic sediments by polycyclic aromatic hydrocarbons (PAHs), which represent the largest class of suspected carcinogens (Björseth and Ramdahl, 1985), has been increasing over the last 20 to 40 years (Van Metre and others, 2000). PAHs in the environment largely are a product of the incomplete combustion of petroleum, oil, coal, and wood (Edwards, 1983). Suspected sources in the urban environment include vehicles, home heating with wood and coal, and power plants (Sims and Overcash, 1983).

During 2001–02, samples of creek bed sediment collected near seal-coated parking lots in Austin, Tex., by the City of Austin had unusually elevated PAH concentrations (Austin American Statesman, 2003a). In 2003, sediment collected by the City of Austin from several parking lot surfaces in Austin had PAH concentrations that exceeded sediment quality guidelines for health of benthic aquatic organisms (MacDonald and others, 2000) by more than two orders of magnitude, prompting city staff to theorize that the sealers coating the parking lots could be the cause (Austin American Statesman, 2003b).

In the United States, sealers are applied to parking lots and driveways to enhance appearance and to protect the underlying asphalt pavement. The most commonly used sealers have a coal-tar-emulsion base, although asphalt-emulsion-based sealers also are available. Reapplication is recommended about every 2 to 3 years. City of Austin staff estimate that about 660,000 gallons (2,500 cubic meters) of coal-tar-emulsion-based sealers are used annually in Austin (City of Austin, 2004). Although figures on national use are not available, The Blue Book of Building and Construction, a directory for the construction industry (Contractors Register, Inc., 2004), lists more than 3,500 pavement sealer companies in 30 states. As an example of sealer use, one commercial sealer applicator, New England Sealcoating, estimates that it has sealed more than 325,000,000 square feet (about 30 square kilometers) of pavement (New England Sealcoating, 2003).

Although coal-tar-emulsion-based and asphalt-emulsion-based sealers are both shiny black, they are produced through

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Table 1. Selected characteristics of sites for sampling simulated rainfall runoff from parking lots, Austin, Texas, 2003.

[--, not applicable]

Type of site	USGS site ID	Site name	Type of surface	Date sealant applied
Test plot	301725097415201	MON	coal-tar-emulsion-sealed	August 5-6, 2003
Test plot	301724097415101	TAR	coal-tar-emulsion-sealed	August 5-6, 2003
Test plot	301726097415301	PAV	asphalt-emulsion-sealed	August 5-6, 2003
Test plot	301724097415201	ASP	unsealed asphalt	--
Synoptic/parking lot in use	301431097465201	CNR	coal-tar-emulsion-sealed	July 2003
Synoptic/parking lot in use	301705097434001	LBJ	coal-tar-emulsion-sealed	July 2003
Synoptic/parking lot in use	301622097415801	OSL	coal-tar-emulsion-sealed	July 1999
Synoptic/parking lot in use	302337097402601	TCQ	coal-tar-emulsion-sealed	March 2003
Synoptic/parking lot in use	301533097431201	UNF	coal-tar-emulsion-sealed	November 2000
Synoptic/parking lot in use	301726097441801	UTN	coal-tar-emulsion-sealed	July 2003
Synoptic/parking lot in use	302640097481601	SSE	asphalt-emulsion-sealed	June 2003
Synoptic/parking lot in use	301651097434901	SOC	asphalt-emulsion-sealed	July 2003
Synoptic/parking lot in use	302724097475701	WWB	asphalt-emulsion-sealed	June 2003
Synoptic/parking lot in use	302700097443101	LAC	unsealed concrete	--
Synoptic/parking lot in use	302153097442301	LOW	unsealed concrete	--
Synoptic/parking lot in use	302003097450301	NWR	unsealed asphalt	--
Synoptic/parking lot in use	301557097462701	ZLK	unsealed asphalt	--

different processes and have different molecular structures. Coal tar is derived from the destructive distillation of coal to produce coke and gas or gas. Coal tar is 50-percent or more PAHs by weight (U.S. Department of Health and Human Services, 2002), and coal-tar-emulsion-based sealers typically are 20- to 35-percent coal tar by weight (for example, STAR, Inc., 1996; Neyra Industries, 2000; SealMaster, 2002). Coal tar is a known human carcinogen, and wastes containing coal tar are subject to reporting under the U.S. Environmental Protection Agency's hazardous waste disposal rule (U.S. Department of Health and Human Services, 2002). In contrast, asphalt is derived from the refining of crude petroleum and contains concentrations of PAHs that are several orders of magnitude less than coal tar (Takada and others, 1990). Analyses of commercially available coal-tar-emulsion-based sealers indicated concentrations of total PAH (sum of 16 parent PAHs) ranging from 5 to 600 times greater than those in asphalt-emulsion-based sealers (City of Austin, 2004).

Data collected by the City of Austin indicate that parking lot sealers contain extremely high concentrations of PAHs compared to those in aquatic sediments and compared to sediment quality guidelines. The questions remain, however, whether PAHs from parking lot sealers are mobile and whether they might contribute to the high concentrations of PAHs often found in urban waterways. The purpose of this study was to

determine concentrations and loads of PAHs in runoff from different types of parking lot surfaces, and to the extent possible, to determine to what degree parking lot sealers are a source of urban PAHs. To investigate the possibility that PAHs from sealed parking lots might be transported to urban creeks, the U.S. Geological Survey (USGS), in cooperation with the City of Austin, sampled runoff and scrapings from four test plots and 13 urban parking lots during August 12–October 6, 2003.

Purpose and Scope

The purpose of this report is to present sampling methods used for this study and the resulting chemical data. Two experimental approaches were taken: (1) repeated sampling of four test plots (three newly sealed and one unsealed) not exposed to vehicle use, and (2) synoptic sampling of parking lots in use with different types of surfaces, both sealed and unsealed. The test plots were in the parking lot at Robert Mueller Municipal Airport, Austin, Tex., which has not been in use since 1999. Immediately before the beginning of the study, a coal-tar-emulsion sealer was applied to two of the test plots, an asphalt-emulsion-sealer was applied to one of the test plots, and a control site was not sealed (the entire lot was sealed many years ago, but the sealer appears to have worn off) (table 1). Three

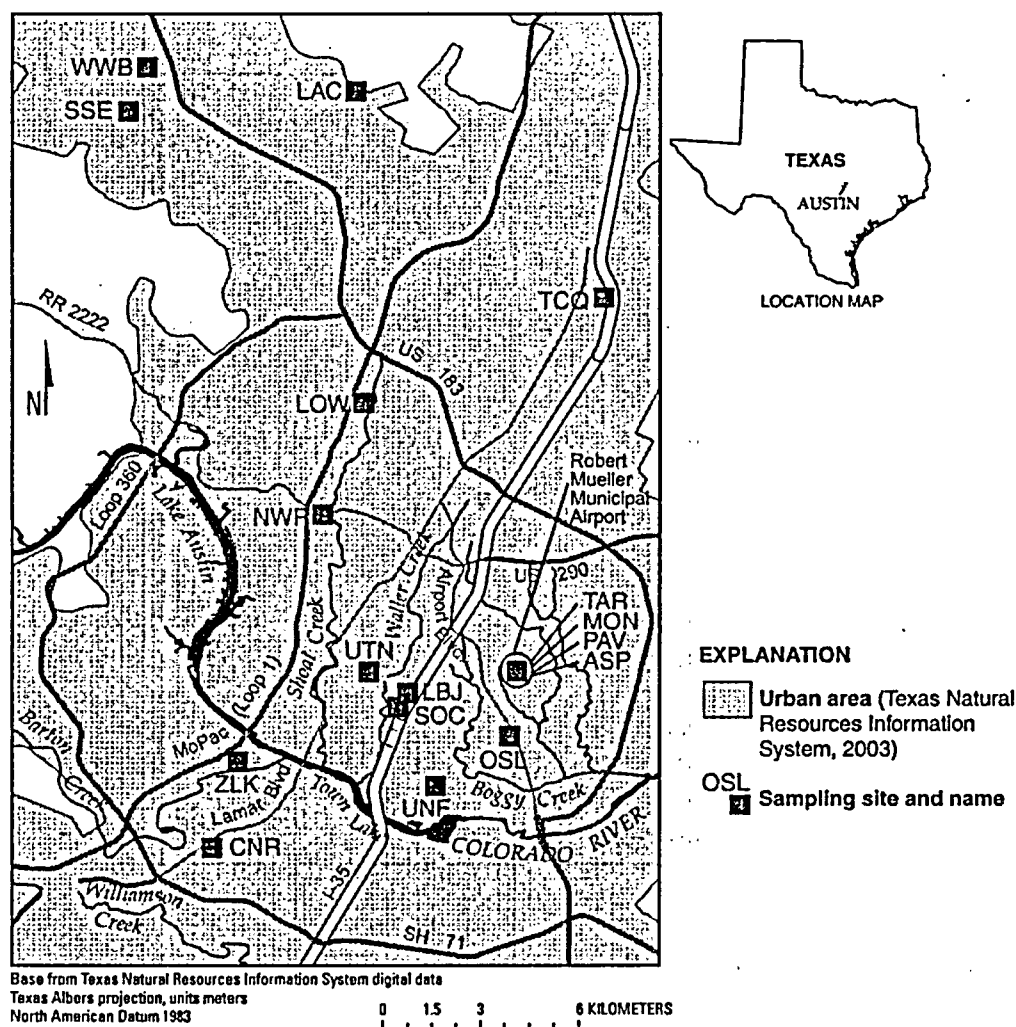


Figure 1. Location of parking lots for sampling of simulated runoff, Austin, Texas, 2003.

times during the 2-month period following application of sealer, distilled deionized (DI) water was applied to the sites using a gentle spray and the washoff was sampled. The sites for the synoptic sampling were in the urban area of Austin (fig. 1). Coal-tar-emulsion-based sealer was applied to six of the parking lots, asphalt-emulsion-based sealer was applied to three parking lots, two lots were unsealed asphalt, and two lots were unsealed concrete (table 1). Each site was sampled once, using the same approach as that used for the test plots. Because the washoff was assumed to contain atmospherically deposited particulates and, in the case of the parking lots in use, particulates from vehicle tires and undercarriages, scrapings of the parking lot surface from most of the sites were analyzed to determine the chemical composition of the surface. Washoff samples were analyzed for a suite of PAHs, major elements, and trace elements in the particulate phase; the scrapings were analyzed for the same suite of PAHs. At a subset of sites, PAHs in the dissolved phase also were analyzed.

Site Selection

The test plots were in the parking lot of Robert Mueller Municipal Airport (fig. 1). The airport was closed in 1999, and the parking lot has been in minimal use since then. Sometime before 1999, a coal-tar sealer was applied, which appeared to have worn off by the time of this study. Three of the test plots are 11- by 11-meter areas that were sealed during August 5–6, 2004 (table 1). The City of Austin arranged for a commercial pavement-sealing company to apply a coal-tar sealer (less than 34-percent coal tar by weight) to one site (TAR) and an asphalt sealer (less than 35-percent asphalt resin by weight) to one site (PAV). An off-the-shelf coal-tar sealer (33-percent coal tar by weight), of the type used for homeowner application to residential driveways, was applied to one site (MON) by City of Austin staff following the manufacturer's instructions. No sealer was applied to the control site (ASP). The test plots received

virtually no vehicle traffic during the 2-month duration of the sampling.

The parking lots for the synoptic sampling were chosen by City of Austin and USGS personnel to represent a range of surface types and sealer ages (table 1). The type of sealer used and date of sealer application were determined on the basis of information provided by the property owner or manager or from the company that sealed the parking lot. Parking lots of schools, government agencies, municipal facilities, and commercial businesses were chosen to sample various locations in the Austin urban area (fig. 1); all parking lots receive daily vehicle traffic.

Sample-Collection Methods

Parking lots were sprinkled with simulated rainfall following a minimum of 5 dry days. Rainfall runoff was simulated using 100 liters of DI water sprayed onto a 5- by 10-meter area of the test plots and parking lots. The only exception was the sampling of the test plots on August 12, 2003, when 25 liters of water on a 2.5- by 5-meter area was used on all the test plots except TAR, the test plot with a commercially applied coal-tar sealer (the smaller volume of water was used because it was immediately obvious that insufficient particulates were available for analysis, so samples for analysis of dissolved PAH only were collected). In one instance it rained during the sampling, and actual rainfall runoff was collected instead of the simulated rainfall (TAR test plot, August 26, 2003). To simulate rainfall, water was pumped with a peristaltic pump from 50-liter, high-density polyethylene (HDPE) carboys through Tygon tubing and a plastic hand-held sprayer (spray rate of about 7 liters per minute) and sprinkled onto the parking lot surface from a height of about 0.75 to 1 meter. Water was blocked at the downslope end of the site either with boards to which weather-stripping had been attached (test plots, August 12 and 21, 2003) or with urethane spill berms (all other samples). The collected runoff was pumped into HDPE carboys through Tygon tubing using a second peristaltic pump. Sampling equipment was cleaned between sites with phosphate-free detergent and then rinsed with tap water, DI water, and methanol.

Samples were pre-processed for analysis at the USGS laboratory in Austin. Samples were filtered through 0.45-micron pore size, polytetrafluoroethylene (PTFE) filters following the methods of Mahler and Van Metre (2003). A stainless steel plate filter holder was used for filtration of particulates for PAH analysis. The filters were massaged inside of locking bags to remove retained particles, and the recovered particles were shipped as chilled slurries in cleaned glass vials to the USGS National Water Quality Laboratory (NWQL) for analysis. In some cases the filtrate also was shipped, chilled and in clean amber glass bottles, to the NWQL for analysis of dissolved PAH. An acrylic filter holder was used for filtration of particulates for major and trace element analysis. The recovered particulates were freeze-dried and ground before submitting to the NWQL. In all cases, sample-processing equipment was cleaned

between samples with phosphate-free detergent, then rinsed with tap water followed by DI water. All equipment used for processing samples for PAH analysis was given a final rinse with methanol.

The test plot and parking lot scrapings were obtained by scraping a small area (less than 0.25 square meter) with a metal paint scraper. The particulates removed were brushed onto a piece of new cardstock and then into a cleaned glass jar. The paint scraper was cleaned between sites in the same manner as the other sampling equipment, and a new brush was used at each site.

Analytical Methods

PAHs in the Particulate Phase

Samples were prepared by extracting about 0.5 gram dry weight of sample (mean 0.47 gram, range 0.10 to 1.36 grams) using pressurized liquid extraction at 120 and 200 degrees Celsius with a mixture of water and isopropyl alcohol (50:50 and 20:80 for the two temperatures, respectively). The samples were extracted for 40 minutes at each temperature at a pressure of 13,790 kilopascals. Surrogate compounds were added to the sample prior to extraction to verify method recoveries. Following extraction, a buffer was added to the extract, and the extract was cleaned using polystyrene divinylbenzene and florisil solid-phase extraction cartridges. The extract was concentrated, solvent exchanged to ethyl acetate, and diluted to 10 milliliters. An internal standard mixture was added to an aliquot of the extract, and the extract was analyzed by full scan on a Hewlett-Packard 5973 gas chromatography/mass spectrometry (GC/MS) system. Difficult sample matrices were diluted before the full-scan analysis, and diluted surrogates were estimated in the samples.

Compound identifications were based on comparison of gas chromatographic peak retention times and mass spectra to those of authentic standard compounds for the target compounds. Response factors were calculated for each compound from a set of calibration standards. For many of the alkyl-substituted PAHs, no authentic standard compounds were available, so the isomers were identified by matching mass spectra in samples with known mass spectra in computerized reference library software (National Institute of Standards and Technology, 2002). The alkyl-substituted PAHs for which standards were not available were quantified using response factors generated from one of the authentic alkyl-homologue compounds in the same alkyl-homologue series. For example, there was no authentic standard for the C4-naphthalene homologue group, so the response factor generated in the calibration standards for 2,6-dimethylnaphthalene was used for its quantitation. The parent PAH response factor was used when no authentic standard was available for a related alkyl-substituted compound within

the same homologue series. Quantitation was done following the methods of Olson and others (in press).

For PAHs in the particulate phase, the estimated method reporting level (MRL) is 5 micrograms per kilogram ($\mu\text{g}/\text{kg}$) for a 25-gram sample. If less than 25 grams was extracted, the MRL was raised accordingly. In some cases, MRLs were raised because of background interferences.

PAHs in the Dissolved Phase

Samples were analyzed following the method described in Fishman (1993), with the difference that continuous liquid-liquid extraction was substituted for use of the separatory funnel. In brief, 1-liter samples fortified with surrogate compounds were extracted by continuous liquid-liquid extraction for 6 hours under acidic then basic conditions. Internal standards were added and sample extracts concentrated to 1 milliliter. Samples were analyzed by GC/MS in electron impact mode. Sample identifications were made by matching retention times and mass spectra with those of standard compounds. Quantitation involved use of internal standards and calibration curves generated by standard compounds of known amounts.

Major and Trace Elements in the Particulate Phase

For major and trace element analyses, samples were freeze-dried and ground to a powder, and elemental concentrations (with the exception of mercury) were determined on concentrated-acid digests (nitric-hydrofluoric-perchloric acids) by inductively coupled plasma/mass spectrometry (ICP/MS) (Briggs and Meier, 2003). Concentrations of mercury were determined by cold-vapor atomic adsorption spectroscopy (Brown and others, 2003).

Quality-Control Samples

Quality-control (QC) samples consist of environmental QC samples and internal laboratory QC samples. Results of QC analyses are summarized below, and detailed results are available from the USGS office in Austin upon request. For this study, two duplicate samples for analysis of particulate PAH were collected, one from a site with extremely elevated particulate PAH concentrations (greater than 4,000,000 $\mu\text{g}/\text{kg}$ total particulate PAH [$\Sigma\text{PAH}_{\text{part}}$]). $\Sigma\text{PAH}_{\text{part}}$ is defined here as the sum of concentrations of 12 parent PAHs (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[a]pyrene, and dibenzo[a,h]anthracene) and 2-methylnaphthalene (Ingersoll and others, 2000). For one of the duplicate samples, $\Sigma\text{PAH}_{\text{part}}$ differed by 8 percent (relative percent difference); for the second duplicate (sample with elevated concentrations), $\Sigma\text{PAH}_{\text{part}}$ differed by 54 percent. One equip-

ment blank was analyzed for dissolved PAH. Three parent PAHs—fluoranthene, phenanthrene, and pyrene—were detected in the blank, but at concentrations more than an order of magnitude less than the MRL. The concentrations were about one-half the concentrations in the environmental sample with the lowest concentrations (ZLK) and less than 1 percent of concentrations in the environmental sample with the highest concentrations (MON).

Laboratory QC samples for particulate PAH analyses consisted of analysis of spiked samples, blanks, and samples of certified reference material (CRM). The surrogate, spike, and CRM values were reported in percent recovered. The method spike was spiked at 20 $\mu\text{g}/\text{kg}$. Because a custom method was used, with limited recovery data, QC criteria are provisional. Representative spike recovery and precision data can be found in Furlong and others (1996). Recovery of the six spiked samples ranged from 6 to 107 percent with a median of 76 percent. For the six laboratory blanks, an analyte was detected in 85 of 336 possible cases, but only 22 detected concentrations were greater than the MRL. The detected concentrations ranged from 0.1 to 3.5 percent of the lowest concentration for that analyte in an environmental sample. For the two analyses of CRM, the recoveries were within the NWQL-established acceptable range for 83 percent of the cases.

Five duplicate samples were analyzed for major and trace elements. Median relative percent difference between the duplicate and environmental samples was 4 percent, with a 25th percentile of 1.4 percent and a 75th percentile of 13 percent. Precision and accuracy of analyses of CRMs, performed internally by the NWQL, were within acceptable limits established by the laboratory (Briggs and Meier, 2003).

PAHs and Major and Trace Elements in Simulated Rainfall Runoff

Results for PAHs and major and trace elements in the simulated rainfall runoff samples are listed in tables 2–4 (at end of report). The “E” qualifier preceding a concentration in the tables indicates that the value is estimated. It is used when QC criteria continually failed upon rerunning samples or when compound quantification was questionable because of interferences. The “E” qualifier also precedes a concentration when it is less than the MRL, when the analyte failed the lab-spike criteria, and for all of the alkyl-homologue groups for which authentic standards are unavailable.

PAHs

Runoff From Test Plots

The test plots were washed off three times during the course of 2 months. Concentrations of $\Sigma\text{PAH}_{\text{part}}$ during the

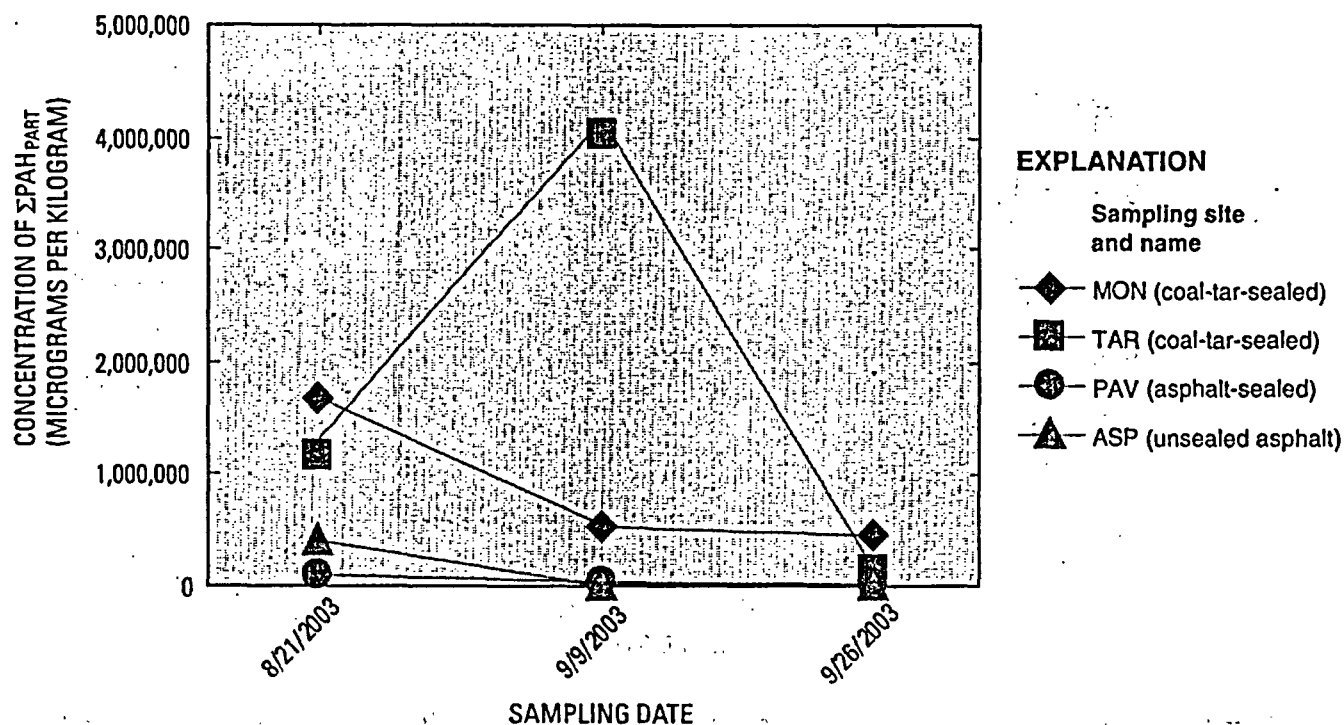


Figure 2. Concentrations of total particulate polycyclic aromatic hydrocarbons ($\Sigma\text{PAH}_{\text{part}}$) in runoff samples from four test plots in Austin, Texas, 2003.

three washoff samplings for the four types of surfaces are shown in figure 2. $\Sigma\text{PAH}_{\text{part}}$ concentrations in the simulated rainfall runoff for each washoff sampling were greater in the coal-tar-sealed test plots than in the asphalt-sealed and unsealed test plots (table 2). Concentrations at three of the test plots, including the control site (ASP), decreased during the course of the three washoff samplings; concentration at one of the coal-tar-sealed test plots increased then decreased. The probable effect concentration (PEC), the concentration above which adverse effects on benthic biota are expected to occur more often than not (MacDonald and others, 2000), is 22,800 $\mu\text{g/kg}$ for $\Sigma\text{PAH}_{\text{part}}$. Concentrations of $\Sigma\text{PAH}_{\text{part}}$ exceeded the PEC in all samples except the final sample collected at the control site.

Concentrations of total dissolved PAH ($\Sigma\text{PAH}_{\text{diss}}$, defined as the sum of the same PAHs as $\Sigma\text{PAH}_{\text{part}}$ excluding 2-methylnaphthalene) during the three washoff samplings are shown in figure 3. $\Sigma\text{PAH}_{\text{diss}}$ concentrations were about an order of magnitude greater in samples from the coal-tar-sealed test plots than concentrations in samples from the asphalt-sealed test plot, which in turn were about an order of magnitude greater than those from the unsealed test plot (control site ASP). Concentrations decreased over time at all sealed test plots but generally stayed the same at the control site. Of 17 PAHs analyzed for, nine were detected (table 3). Four PAHs (acenaphthylene,

acenaphthene, chrysene, and fluorene) were detected only in runoff from the coal-tar-sealed test plots; anthracene was detected in runoff from all the sealed test plots but not from the control site.

Runoff From Parking Lots in Use

Concentrations of $\Sigma\text{PAH}_{\text{part}}$ in simulated rainfall runoff samples from parking lots in use are shown in figure 4, grouped by type of surface. The average $\Sigma\text{PAH}_{\text{part}}$ concentrations in runoff from parking lots in use were 3,500,000 $\mu\text{g/kg}$ (coal-tar-sealed lots), 620,000 $\mu\text{g/kg}$ (asphalt-sealed lots), and 54,000 $\mu\text{g/kg}$ (unsealed asphalt and concrete lots combined). Differences between types of surface were compared using the nonparametric Kruskal-Wallis test; the hypothesis (no difference between groups) was rejected for $p < .1$. The concentration of $\Sigma\text{PAH}_{\text{part}}$ in runoff samples from coal-tar-sealed parking lots was significantly greater than concentrations in samples from other types of surface. Differences between concentrations from other groups were not significant in Kruskal-Wallis tests. The concentrations of $\Sigma\text{PAH}_{\text{part}}$ in runoff samples from parking lots in use are similar to concentrations in samples from test plots with the same type of surface (fig. 4). $\Sigma\text{PAH}_{\text{part}}$ concentrations in all runoff samples from parking lots exceeded the

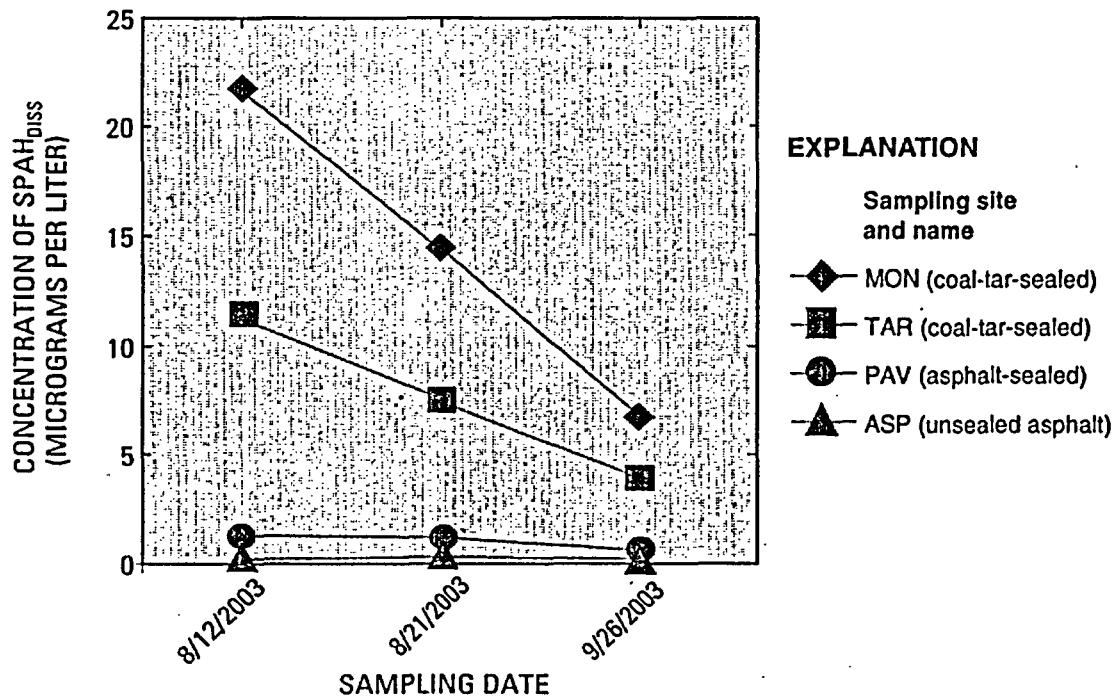


Figure 3. Concentrations of total dissolved polycyclic aromatic hydrocarbons ($\Sigma\text{PAH}_{\text{diss}}$) in runoff samples from four test plots in Austin, Texas, 2003.

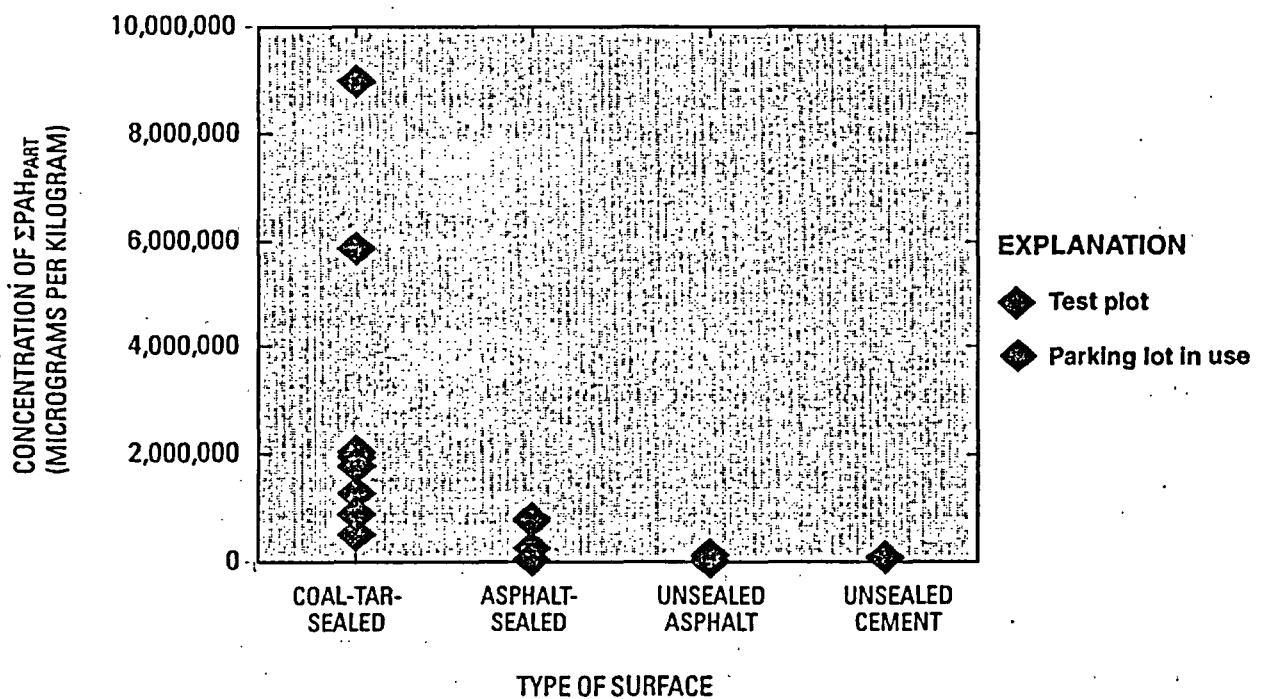


Figure 4. Concentrations of total particulate polycyclic aromatic hydrocarbons ($\Sigma\text{PAH}_{\text{part}}$) in runoff samples from test plots and parking lots in use, Austin, Texas, 2003. Data for test plots is the average of the three washoff samplings at each site.

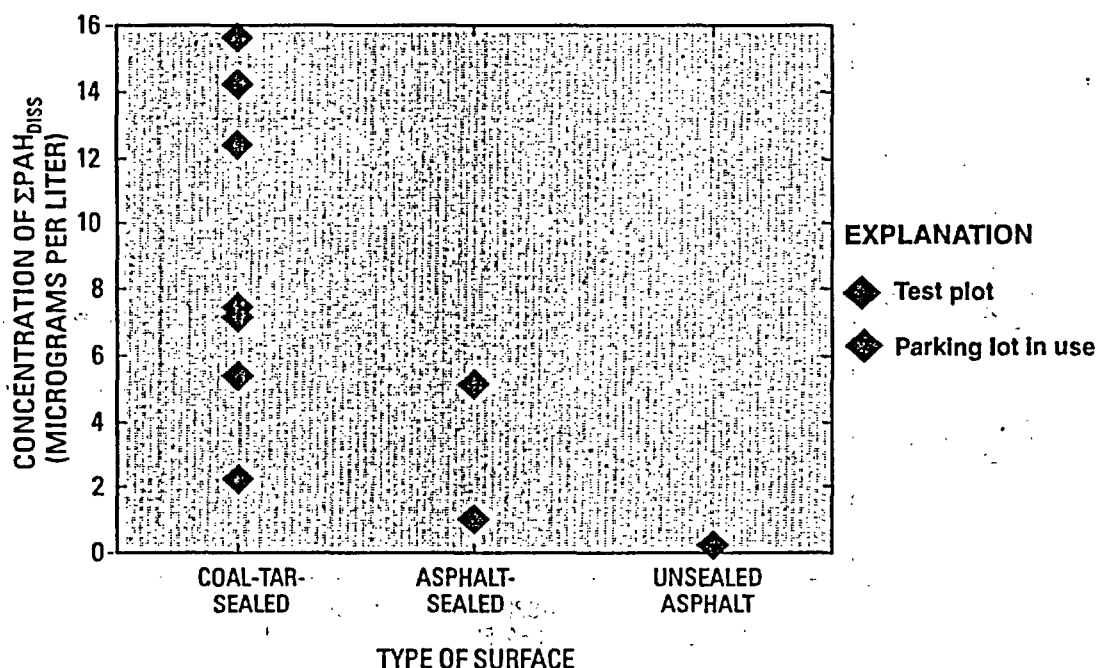


Figure 5. Concentrations of total dissolved polycyclic aromatic hydrocarbons ($\Sigma\text{PAH}_{\text{diss}}$) in runoff samples from test plots and parking lots in use, Austin, Texas, 2003. Data for test plots is the average of the three washoff samplings at each site.

PEC (22,800 µg/kg) except in one sample from an unsealed asphalt lot (ZLK, table 2).

Concentrations of $\Sigma\text{PAH}_{\text{diss}}$ were analyzed at seven of the 13 parking lots in use (fig. 5, table 3). Only one sample from an asphalt-sealed lot was analyzed, so the difference between sealer types could not be compared statistically. The average $\Sigma\text{PAH}_{\text{diss}}$ concentration in filtered water from parking lots in use was 8.6 micrograms per liter (µg/L) for coal-tar-sealed lots; the one sample analyzed from an asphalt-sealed lot had a concentration of 5.1 µg/L, and the one sample analyzed from an unsealed asphalt lot was 0.24 µg/L. Similar to PAHs detected in samples from test plots, acenaphthylene, acenaphthene, and fluorene were detected in samples from one or more of the coal-tar-sealed parking lots but were not detected in samples from the asphalt-sealed or unsealed lots (table 3); however, chrysene was detected in the sample from the asphalt-sealed lot. Concentrations of $\Sigma\text{PAH}_{\text{diss}}$ in runoff samples from parking lots in use were similar to those from test plots with the same type of sealer, except the $\Sigma\text{PAH}_{\text{diss}}$ concentration in the runoff sample from the asphalt-sealed parking lot, which was about four times greater than the average concentration at the asphalt-sealed test plot (fig. 5).

Scrapings

Scrapings are grouped by type of surface (coal-tar-sealed, asphalt-sealed, and unsealed asphalt) for comparison of $\Sigma\text{PAH}_{\text{part}}$ (fig. 6, table 2). The average $\Sigma\text{PAH}_{\text{part}}$ concentration in scrapings sampled from coal-tar-sealed lots was 23,000,000

µg/kg, or 28 times the concentration in scrapings from the asphalt-sealed lots (820,000 µg/kg), which in turn was 59 times the concentration in scrapings from the unsealed asphalt lots (14,000 µg/kg). The maximum $\Sigma\text{PAH}_{\text{part}}$ concentration detected (83,000,000 µg/kg, or 8.3 percent by weight) was in scrapings of the off-the-shelf coal-tar sealer. $\Sigma\text{PAH}_{\text{part}}$ concentrations in scrapings from all sealed test plots or parking lots exceeded the PEC (22,800 µg/kg), and the average concentration in scrapings from coal-tar-sealed lots exceeded the PEC by three orders of magnitude. Concentrations in the two samples of scrapings from unsealed asphalt parking lots (NWR and ZLK) were less than the PEC.

Major and Trace Elements (Metals)

Runoff from Test Plots

Major elements in particulates washed off the test plots were variable from one washoff sampling to the next, and there was no systematic difference in concentrations between type of surface (table 4). PECs have been established for eight trace elements—arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc (MacDonald and others, 2000). During the three washoff samplings, a PEC was exceeded seven times: the PEC for cadmium (4.98 milligrams per kilogram [mg/kg]) was exceeded in one sample from test plot TAR; the PEC for lead (128 mg/kg) was exceeded in one sample each from test plots

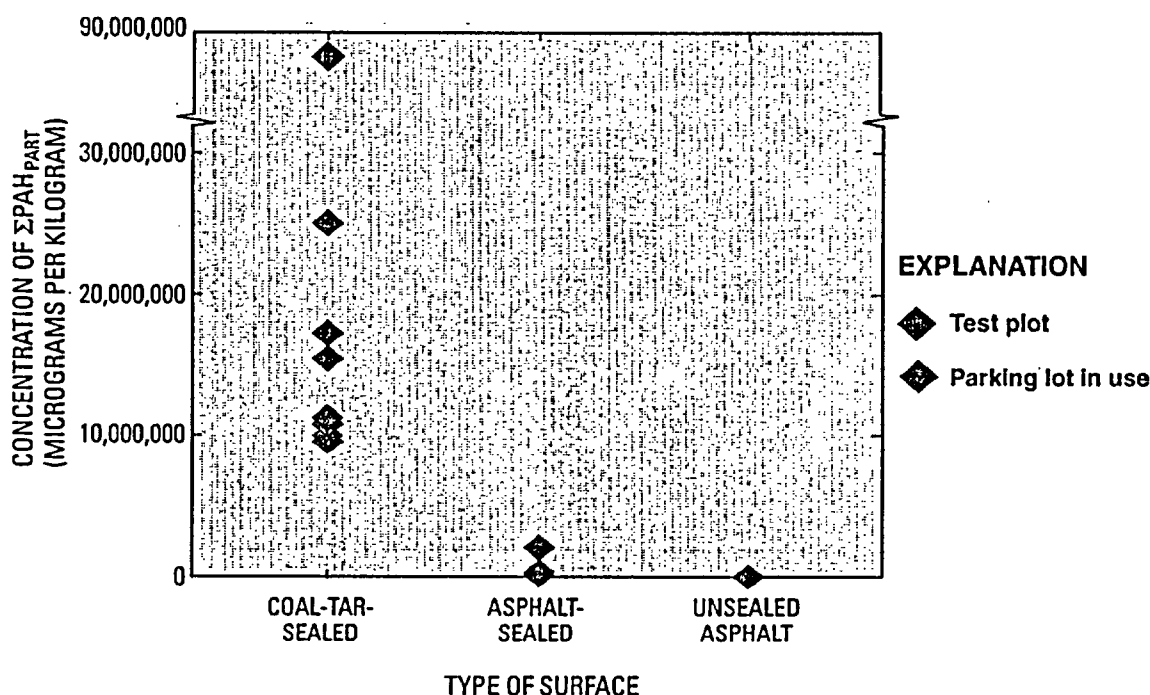


Figure 6. Concentrations of total particulate polycyclic aromatic hydrocarbons ($\Sigma\text{PAH}_{\text{part}}$) in scrapings samples from test plot and parking lot surfaces in Austin, Texas, 2003.

ASP, MON, and PAV; and the PEC for zinc (459 mg/kg) was exceeded in the same samples from ASP, MON, and PAV.

Runoff from Parking Lots in Use

Concentrations of two major elements, calcium and magnesium, were greater in the particulates washed from unsealed parking lots than in those from the sealed parking lots (table 4). Concentrations of other major elements analyzed did not vary on the basis of type of surface. Similar to the results from the test plots, lead and zinc were the trace elements most elevated in particulates washed from the parking lots on the basis of comparison to PECs. The PEC for lead was exceeded in samples from some coal-tar-sealed parking lots (TCQ, OSL, LBJ, and UTN) and in samples from both unsealed concrete lots (LAC, LOW), but the PEC was not exceeded in any of the samples from asphalt-sealed or unsealed asphalt parking lots. The PEC for zinc was exceeded in samples from every parking lot except WWB (asphalt-sealed), ZLK (unsealed asphalt), and OSL (coal-tar-sealed).

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Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

[In micrograms per kilogram. $\Sigma\text{PAH}_{\text{part}}$, total particulate polycyclic aromatic hydrocarbons (for complete definition see text); E, estimated; <, less than. Note: Data available in USGS National Water Information System (NWIS) database.]

Site name	Type of surface	Sampling date	Sample type	Batch no.	$\Sigma\text{PAH}_{\text{part}}$	Phenol	p-Cresol	Naphthalene	C1-1 isomer methyl Naphthalene
Test plots									
MON	coal-tar-emulsion-sealed	8/21/2003	washoff	8022R03238	1,700,000	E3,000	E1,700	12,000	E7
TAR	coal-tar-emulsion-sealed	8/21/2003	washoff	8022R03238	1,200,000	E7,100	E2,000	E6,400	E2
PAV	asphalt-emulsion-sealed	8/21/2003	washoff	8022R03238	96,000	E13,000	E2,200	<19,000	<19
ASP	unsealed asphalt	8/21/2003	washoff	8022R03238	410,000	E1,300	E690	E2,300	<6
MON	coal-tar-emulsion-sealed	9/9/2003	washoff	8022R03245	530,000	<8,500	<8,500	E5,800	<8
TAR	coal-tar-emulsion-sealed	9/9/2003	washoff	8022R03245	4,000,000	<25,000	<25,000	E24,000	<30
PAV	asphalt-emulsion-sealed	9/9/2003	washoff	8022R03245	40,000	5,200	E650	E570	<1
ASP	unsealed asphalt	9/9/2003	washoff	8022R03245	25,000	E690	E410	<1,000	<1
MON	coal-tar-emulsion-sealed	9/26/2003	washoff	8022R03276	460,000	<3,500	<3,500	E2,800	<3
TAR	coal-tar-emulsion-sealed	9/26/2003	washoff	8022R03276	140,000	<3,500	<3,500	<3,500	<3
PAV	asphalt-emulsion-sealed	9/26/2003	washoff	8022R03276	28,000	E2,800	<4,000	<4,000	<4
ASP	unsealed asphalt	9/26/2003	washoff	8022R03276	14,000	<5,000	<5,000	<5,000	<5
MON	coal-tar-emulsion-sealed	8/12/2003	scraping	8022R03245	83,000,000	E20,000	38,000	4,400,000	E1
TAR	coal-tar-emulsion-sealed	8/12/2003	scraping	8022R03245	11,000,000	E7,300	<12,000	64,000	E32
PAV	asphalt-emulsion-sealed	8/12/2003	scraping	8022R03245	110,000	7,300	E1,400	E1,200	<2
Parking lots in use									
TCQ	coal-tar-emulsion-sealed	9/7/2003	washoff	8022R03245	2,000,000	<6,800	<6,800	18,000	E7
SSE	asphalt-emulsion-sealed	9/7/2003	washoff	8022R03245	260,000	E2,600	<6,800	E4,800	<6
SSE duplicate	asphalt-emulsion-sealed	9/7/2003	washoff	8022R03245	240,000	<5,500	<5,500	E4,200	<5
WWB	asphalt-emulsion-sealed	9/7/2003	washoff	8022R03245	830,000	<4,000	<4,000	4,500	E3
LAC	unsealed concrete	9/8/2003	washoff	8022R03245	75,000	<2,500	<2,500	E1,500	<2

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	Type of surface	Sampling date	Sample type	Batch no.	$\Sigma\text{PAH}_{\text{part}}$	Phenol	p-Cresol	Naphthalene	C1-1 isomer methyl Naphth
Parking lots in use—Continued									
LOW	unsealed concrete	9/8/2003	washoff	8022R03245	69,000	<2,000	<2,000	E1,100	<2
NWR	unsealed asphalt	9/8/2003	washoff	8022R03245	64,000	<4,500	<4,500	E2,900	<4
LBJ	coal-tar-emulsion-sealed	9/28/2003	washoff	8022R03281	9,000,000	E19,000	<17,000	E14,000	E19
UTN	coal-tar-emulsion-sealed	9/28/2003	washoff	8022R03281	2,000,000	E4,600	<4,500	6,700	<4
SOC	asphalt-emulsion-sealed	9/28/2003	washoff	8022R03281	770,000	E14,000	<12,000	<12,000	<12
CNR	coal-tar-emulsion-sealed	9/30/2003	washoff	8022R03276	1,300,000	E2,200	E1,400	E6,500	<3
OSL	coal-tar-emulsion-sealed	9/30/2003	washoff	8022R03276	520,000	<4,000	<4,000	E1,700	<4
UNF	coal-tar-emulsion-sealed	9/30/2003	washoff	8022R03276	7,500,000	E2,900	E2,600	E13,000	E5
UNF duplicate	coal-tar-emulsion-sealed	9/30/2003	washoff	8022R03276	4,300,000	E2,000	E1,500	E9,000	E3
ZLK	unsealed asphalt	9/30/2003	washoff	8022R03276	7,200	<2,000	E2,700	<2,000	<2
TCQ	coal-tar-emulsion-sealed	9/14/2003	scraping	8022R03245	25,000,000	<25,000	E10,000	320,000	E160
SSE	asphalt-emulsion-sealed	9/14/2003	scraping	8022R03245	340,000	<12,000	<12,000	E6,000	<12
WWB	asphalt-emulsion-sealed	9/14/2003	scraping	8022R03245	2,000,000	<25,000	<25,000	E17,000	<25
NWR	unsealed asphalt	9/14/2003	scraping	8022R03245	7,100	E270	<500	<500	<
LBJ	coal-tar-emulsion-sealed	9/28/2003	scraping	8022R03281	15,000,000	E9,300	<8,500	31,000	E89
UTN	coal-tar-emulsion-sealed	9/28/2003	scraping	8022R03281	11,000,000	E13,000	<12,000	22,000	<12
CNR	coal-tar-emulsion-sealed	10/6/2003	scraping	8022R03281	9,400,000	E13,000	<12,000	22,000	<12
OSL	coal-tar-emulsion-sealed	10/6/2003	scraping	8022R03281	9,900,000	E12,000	<12,000	17,000	<12
UNF	coal-tar-emulsion-sealed	10/6/2003	scraping	8022R03281	17,000,000	E13,000	<12,000	23,000	<12
ZLK	unsealed asphalt	10/6/2003	scraping	8022R03281	20,000	<8,500	<8,500	<8,500	<8

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	1,6-Dimethyl-naphthalene	C2-128 isomers, C2-alkylated Naphthalenes	Ace-naph-thylene	1,2-Dimethyl-naphthalene	Ace-naph-thene	C3-128 somers, C3-alkylated Naphthalenes	2,3,6-Trimethyl-naphthalene	9H-Fluorene	C4-128 isomers, C4-alkylated Naphthalenes	1-methyl-9H-Fluorene	Phenan-threne
Test plots											
MON	E3,200	E5,800	E3,800	<9,000	14,000	<9,000	<9,000	19,000	<15,000	<9,000	310,00
TAR	E3,400	E4,100	E5,000	<10,000	E5,400	<10,000	<10,000	E7,800	<10,000	<10,000	150,00
PAV	<19,000	<19,000	<19,000	<19,000	<19,000	<19,000	<19,000	<19,000	<19,000	<19,000	E13,00
ASP	<6,700	<6,700	E2,900	<6,700	E2,000	<6,700	<6,700	E2,000	<6,700	<6,700	32,00
MON	<8,500	<8,500	<8,500	<8,500	E6,300	<8,500	<8,500	E5,600	<200,000	<8,500	66,00
TAR	<25,000	<30,000	36,000	<25,000	31,000	<34,000	<25,000	33,000	<800,000	<25,000	470,00
PAV	<1,000	<1,500	E490	<1,000	<1,000	<1,000	<1,000	E600	<22,000	<1,000	5,30
ASP	<1,000	<1,000	<1,000	<1,000	<1,000	<1,000	<1,000	E480	<18,000	<1,000	2,20
MON	<3,500	<3,500	E1,500	<3,500	<3,500	<3,500	<3,500	E2,200	<61,000	<3,500	66,00
TAR	<3,500	<3,500	E1,200	<3,500	<3,500	<3,500	<3,500	E1,600	<58,000	<3,500	12,00
PAV	<4,000	<4,000	<4,000	<4,000	<4,000	<4,000	<4,000	E1,500	<66,000	<4,000	E2,80
ASP	<5,000	<5,000	<5,000	<5,000	<5,000	<5,000	<5,000	<5,000	<46,000	<5,000	E1,40
MON	120,000	E920,000	48,000	57,000	2,700,000	E520,000	40,000	2,800,000	<6,500,000	88,000	19,00
TAR	E11,000	E36,000	19,000	11,000	14,000	E69,000	E11,000	210,000	<950,000	15,000	2,200,00
PAV	<2,500	<2,500	E1,000	<2,500	E1,200	<2,500	<2,500	E2,300	<52,000	<2,500	20,00
Parking lots in use											
TCQ	E6,400	E8,300	12,000	<6,800	15,000	E8,900	<6,800	15,000	<220,000	E4,300	290,00
SSE	<6,800	<6,800	7,500	<6,800	<6,800	<6,800	<6,800	E3,800	<160,000	<6,800	28,00
SSE duplicate	<5,500	<5,500	6,400	<5,500	<5,500	<5,500	<5,500	E3,300	<130,000	<5,500	24,00
WWB	<4,000	<4,000	4,900	<4,000	E3,000	<4,000	<4,000	E2,900	<92,000	<4,000	35,00
LAC	<2,500	<2,500	2,500	<2,500	E1,600	<2,500	<2,500	E1,300	<53,000	<2,500	5,80

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	1,6-Dimethyl-naphthalene	C2-128 isomers, C2-alkylated Naphthalenes	Ace-naph-thylene	1,2-Dimethyl-naphthalene	Ace-naph-thene	C3-128 somers, C3-alkylated Naphthalenes	2,3,6-Trimethyl-naphthalene	9H-Fluorene	C4-128 isomers, C4-alkylated Naphthalenes	1-methyl-9H-Fluorene	Phenan-threne
Parking lots in use—Continued											
LOW	<2,000	<2,000	E2,000	<2,000	E1,300	<2,000	<2,000	E1,000	<40,000	<2,000	5,50
NWR	<4,500	<4,500	E4,200	<4,500	<4,500	<4,500	<4,500	E2,200	<90,000	<4,500	6,60
LBJ	<17,000	<17,000	36,000	<17,000	31,000	<21,000	<17,000	32,000	<340,000	E9,900	960,00
UTN	<4,500	<4,500	E4,300	<4,500	E2,100	<4,500	<3,500	4,600	<91,000	<4,500	69,00
SOC	<12,000	<12,000	E7,600	<12,000	<12,000	<12,000	<12,000	E7,900	<230,000	<12,000	88,00
CNR	<3,500	<3,500	3,800	<3,500	E1,300	<3,500	<3,500	3,600	<65,000	E1,400	94,00
OSL	<4,000	<4,000	E2,800	<4,000	<4,000	<4,000	<4,000	E2,200	<69,000	<4,000	21,00
UNF	<5,000	<5,000	8,900	<5,000	E3,300	<6,000	<5,000	8,500	<120,000	E2,500	310,00
UNF duplicate	<3,500	<3,500	5,600	<3,500	E2,400	<3,500	<3,500	5,600	<81,000	<3,500	180,00
ZLK	<2,000	<2,000	<2,000	<2,000	<2,000	<2,000	<2,000	<2,000	<34,000	<2,000	E72
TCQ	36,000	E150,000	75,000	27,000	420,000	E210,000	32,000	420,000	<1,800,000	37,000	4,500,00
SSE	<12,000	<12,000	<12,000	<12,000	E9,200	<12,000	<12,000	E7,700	<320,000	<12,000	42,00
WWB	<25,000	<25,000	<25,000	<25,000	E19,000	<25,000	<25,000	E16,000	<590,000	<25,000	120,00
NWR	<500	<500	<500	<500	<500	<500	<500	E280	<9,500	<500	97
LBJ	10,000	E53,000	52,000	<8,500	150,000	E72,000	E4,700	120,000	<280,000	9,800	2,900,00
UTN	<12,000	<12,000	15,000	<12,000	E7,600	<12,000	<12,000	16,000	<260,000	E7,700	460,00
CNR	<12,000	<12,000	18,000	<12,000	E11,000	<12,000	<12,000	25,000	<420,000	E9,400	850,00
OSL	<12,000	<12,000	26,000	<12,000	E5,700	<12,000	<12,000	15,000	<260,000	E7,600	390,00
UNF	<12,000	<12,000	18,000	<12,000	E8,000	<12,000	<12,000	20,000	<310,000	E9,200	1,500,00
ZLK	<8,500	<8,500	<8,500	<8,500	<8,500	<8,500	<8,500	<8,500	<15,000	<8,500	<8,50

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	4,5-Methylene-phenanthrene	C1-178 isomers methylated Phenanthrene/anthracenes	1-Methyl-phenanthrene	C2-178 isomers, C2-alkylated Phenanthrene/anthracenes	Fluoranthene	Pyrene	C3-178 isomers, C3-alkylated Phenanthrene/anthracenes	C4-178 isomers, C4-alkylated Phenanthrene/anthracenes	1-Methyl-pyrene	1-methyl-Fluoranthene
Test plots										
MON	29,000	E46,000	9,200	E16,000	510,000	340,000	<9,000	<9,000	E8,300	E12,000
TAR	17,000	E32,000	E7,600	E21,000	320,000	240,000	<20,000	<10,000	E9,600	E9,000
PAV	E6,300	E8,800	<19,000	<19,000	23,000	E17,000	<19,000	<19,000	<19,000	E1,000
ASP	E6,700	E11,000	E3,400	E8,600	110,000	85,000	<8,000	<6,700	E5,100	E4,000
MON	10,000	E18,000	E5,300	E13,000	160,000	110,000	<12,000	<9,500	E8,000	E3,000
TAR	67,000	E120,000	28,000	E89,000	1,100,000	870,000	<82,000	<46,000	44,000	E34,000
PAV	<1,000	E1,600	<1,000	E1,400	11,000	7,000	<1,500	<1,000	E540	E1,000
ASP	<1,000	E1,000	<1,000	<1,000	6,100	4,800	<1,000	<1,000	E460	E1,000
MON	E2,500	E9,900	E1,700	E4,400	160,000	97,000	<3,500	<3,500	E2,100	E2,000
TAR	<3,500	E4,400	<3,500	E3,700	38,000	29,000	<3,500	<3,500	E1,900	E1,000
PAV	<4,000	<4,000	<4,000	<4,000	6,000	4,600	<4,000	<4,000	<4,000	<4,000
ASP	<5,000	<5,000	<5,000	<5,000	E3,000	E2,600	<5,000	<5,000	E970	<4,000
MON	1,900,000	E2,700,000	390,000	E680,000	18,000,000	13,000,000	<250,000	<55,000	260,000	E1,000
TAR	240,000	E420,000	63,000	E220,000	2,800,000	2,200,000	<150,000	<48,000	69,000	E94,000
PAV	E1,300	E5,000	<2,500	E4,300	28,000	21,000	<4,000	<2,500	E1,600	E1,000
Parking lots in use										
TCQ	23,000	E53,000	11,000	E35,000	580,000	460,000	<24,000	<12,000	15,000	E14,000
SSE	E5,700	E12,000	E3,800	E10,000	75,000	41,000	<9,500	<8,000	E5,600	E1,000
SSE duplicate	E4,800	E9,800	E3,300	E8,900	67,000	39,000	<9,000	<7,000	E5,000	E1,000
WWB	6,200	E16,000	4,200	E14,000	270,000	180,000	<12,000	<6,000	6,200	E5,000
LAC	E2,100	E3,800	E1,300	E3,500	18,000	15,000	<3,200	<2,700	E2,100	E1,000

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	4,5-Methylene-phenanthrene	C1-178 isomers methylated Phenanthrene/anthracenes	1-Methyl-phenanthrene	C2-178 isomers, C2-alkylated Phenanthrene/anthracenes	Fluoranthene	Pyrene	C3-178 isomers, C3-alkylated Phenanthrene/anthracenes	C4-178 isomers, C4-alkylated Phenanthrene/anthracenes	1-Methyl-pyrene	C1-ison methr Fluorai pyri
Parking lots in use—Continued										
LOW	E1,700	E3,200	E1,100	E2,700	17,000	14,000	<2,500	<2,100	E1,600	E:
NWR	E3,100	E5,400	E2,000	E5,200	14,000	12,000	<5,500	<5,000	E3,200	E:
LBJ	61,000	E210,000	45,000	E95,000	2,700,000	2,000,000	<40,000	<17,000	44,000	E320
UTN	12,000	E28,000	7,100	E18,000	520,000	420,000	<10,000	<5,000	13,000	E120
SOC	E8,300	E30,000	E6,700	E20,000	260,000	160,000	<18,000	<12,000	E11,000	E40
CNR	9,500	E28,000	5,300	E23,000	360,000	280,000	<15,000	<7,500	7,300	E9:
OSL	E2,500	E10,000	E2,400	E9,200	140,000	100,000	<6,500	<3,500	4,300	E3:
UNF	50,000	E120,000	32,000	E67,000	2,200,000	1,800,000	<27,000	<18,000	44,000	E540
UNF duplicate	25,000	E64,000	17,000	E35,000	1,300,000	1,000,000	<16,000	<5,500	22,000	E260
ZLK	<2,000	<2,000	<2,000	<2,000	E1,700	E1,600	<2,000	<2,000	<2,000	<
TCQ	440,000	E810,000	140,000	E440,000	6,700,000	5,300,000	<260,000	<81,000	160,000	E1,900
SSE	E11,000	E21,000	E7,000	E19,000	91,000	73,000	<18,000	<16,000	E11,000	E2:
WWB	29,000	E62,000	E18,000	E57,000	580,000	440,000	<54,000	<36,000	29,000	E170
NWR	<500	E500	<500	<500	1,500	1,300	<500	<500	<500	
LBJ	150,000	E470,000	90,000	E160,000	4,500,000	3,200,000	<60,000	<12,000	58,000	E490
UTN	100,000	E190,000	46,000	E100,000	3,000,000	2,400,000	<42,000	<17,000	71,000	E690
CNR	130,000	E260,000	50,000	E180,000	2,600,000	2,000,000	<110,000	<43,000	64,000	E700
OSL	81,000	E200,000	45,000	E170,000	2,600,000	2,100,000	<120,000	<30,000	75,000	E660
UNF	210,000	E460,000	96,000	E190,000	5,700,000	4,400,000	<67,000	<17,000	97,000	E920
ZLK	<8,500	<8,500	<8,500	<8,500	E5,400	E4,900	<8,500	<8,500	<8,500	<

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	Benz(a)-anthracene	Chrysene	C3-202 isomers, C3-alkylated Fluoranthene/pyrenes	C1-228 isomers, methylated Benzo(a)-anthracene/chrysenes	C4-202 isomers, C4-alkylated Fluoranthene/pyrenes	C5-202 isomers, C5-alkylated Fluoranthene/pyrenes	C2-228 isomers, C2-alkylated Benzo(a)-anthracene/chrysenes	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Benzo(e)pyrene
Test plots										
MON	110,000	190,000	<9,000	E46,000	<35,000	<9,000	<20,000	160,000	110,000	95,000
TAR	100,000	180,000	<10,000	E54,000	<30,000	<10,000	E24,000	180,000	110,000	100,000
PAV	E9,200	E17,000	<19,000	E8,900	<19,000	<19,000	<19,000	E14,000	E6,900	E10,000
ASP	44,000	60,000	<6,700	E25,000	<9,000	<6,700	E12,000	61,000	45,000	42,000
MON	39,000	70,000	<10,000	E25,000	<22,000	<8,500	<16,000	87,000	48,000	46,000
TAR	350,000	570,000	<41,000	E210,000	<120,000	<42,000	E120,000	560,000	410,000	370,000
PAV	1,900	6,000	<1,000	<2,000	<2,000	<1,000	<1,500	5,600	4,500	4,100
ASP	2,800	3,700	<1,000	<2,000	<1,000	<1,000	<1,000	4,200	3,600	3,000
MON	16,000	80,000	<4,000	E12,000	<22,000	<3,500	<6,500	59,000	39,000	38,000
TAR	14,000	25,000	<3,500	E8,800	<5,000	<3,500	<5,500	21,000	16,000	15,000
PAV	E2,900	E3,800	<4,000	<4,000	<4,000	<4,000	<4,000	7,600	6,300	5,600
ASP	E2,200	E1,900	<5,000	<5,000	<5,000	<5,000	<5,000	E3,700	E3,300	E2,600
MON	5,000,000	5,200,000	<140,000	E1,900,000	<450,000	<150,000	<550,000	4,800,000	4,400,000	3,000,000
TAR	940,000	1,100,000	<30,000	E430,000	<150,000	<45,000	E200,000	1,000,000	730,000	690,000
PAV	10,000	13,000	<2,500	E6,500	<5,000	<4,500	E5,900	12,000	9,800	8,900
Parking lots in use										
TCQ	110,000	310,000	<12,000	E85,000	<77,000	<16,000	<46,000	370,000	170,000	200,000
SSE	15,000	50,000	<8,000	E18,000	<20,000	<10,000	<16,000	66,000	29,000	40,000
SSE duplicate	15,000	47,000	<7,000	E17,000	<16,000	<8,500	<14,000	76,000	20,000	37,000
WWB	48,000	190,000	E8,000	E45,000	<42,000	<10,000	E25,000	220,000	99,000	100,000
LAC	6,800	9,800	<2,500	E6,100	<4,500	<3,000	E4,600	12,000	7,900	9,100

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austin, Texas

[illegible]

Table 2 Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	C3-228 isomers, C3-Benzo(a)-anthracene/chrysenes	C2-252 isomers, C2-alkylated Benzopyrene/ perylenes	C4-228 isomers, C4-Benzo(a)-anthracene/chrysenes	Benzo-(g,h,i)-perylene	Indeno-(1,2,3-c,d)-pyrene	Dibenzo-(a,h)-anthracene	C3-252 isomers, C3-alkylated Benzopyrene/ perylenes	C4-252 isomers, C4-alkylated Benzopyrene/ perylenes	iso C5-bb Anth chr
Test plots									
MON	<10,000	<30,000	<9,000	76,000	90,000	18,000	<15,000	<15,000	<9,0
TAR	<15,000	<35,000	<10,000	86,000	100,000	21,000	<15,000	<11,000	<10,0
PAV	<19,000	<19,000	<19,000	E9,100	E8,400	<19,000	<19,000	<19,000	<19,0
ASP	<6,700	<20,000	<6,700	42,000	48,000	11,000	<8,500	<6,700	<6,7
MON	<14,000	<22,000	<16,000	40,000	E53,000	14,000	<14,000	<12,000	<12,0
TAR	E55,000	<170,000	<95,000	340,000	E280,000	82,000	<80,000	<58,000	<54,0
PAV	<1,500	<4,000	<2,000	5,600	4,900	1,600	<3,000	<2,500	<1,5
ASP	<1,000	<3,000	<1,500	3,500	3,400	1,300	<2,500	<2,500	<1,0
MON	<7,500	<22,000	<7,500	33,000	35,000	6,000	<5,500	<8,500	<3,5
TAR	<3,500	<9,000	<5,000	16,000	16,000	4,800	<5,000	<5,000	<3,5
PAV	<4,000	<7,000	<4,000	7,900	6,400	<4,000	<5,000	<6,000	<4,0
ASP	<5,000	<5,000	<5,000	E3,000	E2,400	<5,000	<5,000	<5,000	<5,0
MON	<150,000	<980,000	<620,000	3,300,000	E4,800,000	280,000	<300,000	<300,000	<45,0
TAR	<35,000	<300,000	<150,000	660,000	E980,000	64,000	<150,000	<65,000	<45,0
PAV	<3,000	<10,000	<5,000	11,000	11,000	<2,500	<9,500	<6,500	<4,5
Parking lots in use									
TCQ	<20,000	E94,000	<38,000	180,000	E260,000	32,000	<41,000	<26,000	<16,0
SSE	<12,000	<15,000	<12,000	38,000	E45,000	10,000	<18,000	<12,000	<12,0
SSE duplicate	<10,000	<20,000	<14,000	34,000	E37,000	9,800	<14,000	<10,000	<11,0
WWB	E10,000	E48,000	<22,000	86,000	E92,000	19,000	<21,000	<14,000	<13,0
LAC	<3,500	<6,500	<4,200	8,300	E8,600	3,600	<5,000	<4,000	<4,0

Table 2. Particulate-phase concentrations of polycyclic aromatic hydrocarbons in washoff and scrapings samples from parking lots, Austi

Site name	C3-228 isomers, C3-Benzo(a)-anthracene/chrysenes	C2-252 isomers, C2-alkylated Benzopyrene/ perylenes	C4-228 isomers, C4-Benzo(a)-anthracene/chrysenes	Benzo-(g,h,i)- perylene	Indeno-(1,2,3-c,d)- pyrene	Dibenzo-(a,h)- anthra- cene	C3-252 isomers, C3-alkylated Benzopyrene/ perylenes	C4-252 isomers, C4-alkylated Benzopyrene/ perylenes	C5-6 Anth chr
Parking lots in use—Continued									
LOW	<2,600	<5,800	<3,400	8,500	E6,300	2,800	<4,000	<3,200	<3,7
NWR	<6,000	<10,000	<6,500	9,800	E12,000	<4,500	<7,500	<6,000	<6,5
LBJ	<40,000	<480,000	<130,000	830,000	960,000	170,000	<160,000	<140,000	<46,0
UTN	<12,000	<150,000	<40,000	290,000	320,000	56,000	<48,000	<46,000	<14,0
SOC	<14,000	<52,000	<22,000	76,000	76,000	23,000	<32,000	<30,000	<23,0
CNR	<14,000	<82,000	<32,000	160,000	170,000	28,000	<30,000	<19,000	<12,0
OSL	<7,500	<49,000	<18,000	72,000	77,000	15,000	<21,000	<11,000	<7,0
UNF	<42,000	<370,000	<130,000	850,000	880,000	220,000	<87,000	<77,000	<26,0
UNF duplicate	<26,000	<21,000	<72,000	520,000	530,000	88,000	<52,000	<38,000	<16,0
ZLK	<2,000	<3,000	<2,000	2,100	E1,600	<2,000	<3,000	<2,500	<2,0
TCQ	<84,000	<760,000	<320,000	1,700,000	E2,500,000	350,000	<280,000	<180,000	<110,0
SSE	<17,000	<25,000	<22,000	31,000	E46,000	18,000	<21,000	<16,000	<21,0
WWB	<48,000	<140,000	<76,000	240,000	E240,000	70,000	<78,000	<52,000	<62,0
NWR	<500	<1,500	<600	980	860	<500	<2,000	<1,500	<6
LBJ	<41,000	<560,000	<150,000	1,000,000	1,200,000	270,000	<150,000	<170,000	<41,0
UTN	<46,000	<610,000	<180,000	1,200,000	1,200,000	260,000	<180,000	<180,000	<52,0
CNR	<31,000	<420,000	<140,000	820,000	940,000	200,000	<160,000	<93,000	<59,0
OSL	<44,000	<770,000	<210,000	1,100,000	1,200,000	280,000	<260,000	<220,000	<79,0
UNF	<43,000	<610,000	<160,000	1,200,000	1,300,000	240,000	<160,000	<150,000	<48,0
ZLK	<8,500	<12,000	<8,500	<8,500	<8,500	<8,500	<12,000	<13,000	<8,5

Table 3. Dissolved-phase concentrations of polycyclic aromatic hydrocarbons in washoff samples from parking lots, Austin, Texas, 2003.[In micrograms per liter. $\Sigma\text{PAH}_{\text{diss}}$, total dissolved polycyclic hydrocarbons (for complete definition see text); E, estimated; <, less than.]

Site name	Type of surface	Sampling date	$\Sigma\text{PAH}_{\text{diss}}$	Ace-naph-thylene	Ace-naph-thene	An-thra-cene	Benzo-[b]-fluoran-thene	Benzo-[k]-fluoran-thene	Benzo-[a]-pyrene	Chry-sene	Fluor-an-thene	9H-Fluor-ene	In-deno-py-rene	Nitro-ben-zene	Phe-nan-threne
Test plots															
MON	coal-tar-emulsion-sealed	8/12/2003	21	E0.56	E0.39	E1.4	<1.9	<1.7	<1.3	<2.7	4.1	E0.94	<3.0	<2.0	11
MON	coal-tar-emulsion-sealed	8/21/2003	14	E.17	E.36	E1.0	<1.9	<1.7	<1.3	<2.7	2.6	E.61	<3.0	<2.0	7.3
MON	coal-tar-emulsion-sealed	9/26/2003	6.9	E.03	E.05	E.29	<1.9	<1.7	<1.3	E.25	2.9	E.13	<3.0	<2.0	E1.9
TAR	coal-tar-emulsion-sealed	8/12/2003	11	E.39	E.31	E1.5	<1.9	<1.7	<1.3	<2.7	E1.0	E.78	<3.0	<2.0	5.5
TAR	coal-tar-emulsion-sealed	8/21/2003	7.3	E.35	<1.8	E.77	<1.9	<1.7	<1.3	<2.7	E1.2	E.37	<3.0	<2.0	2.8
TAR	coal-tar-emulsion-sealed	9/26/2003	3.8	E.14	E.06	E.56	<1.9	<1.7	<1.3	E.05	E1.2	E.14	<3.0	<2.0	E1.0
PAV	asphalt-emulsion-sealed	8/12/2003	1.3	<2.4	<1.8	<2.0	<1.9	<1.7	<1.3	<2.7	E0.31	<2.0	<3.0	<2.0	E.87
PAV	asphalt-emulsion-sealed	8/21/2003	1.2	<2.4	<1.8	E.23	<1.9	<1.7	<1.3	<2.7	E.30	<2.0	<3.0	<2.0	E.52
PAV	asphalt-emulsion-sealed	9/26/2003	.64	<2.4	<1.8	E.09	<1.9	<1.7	<1.3	<2.7	E.18	<2.0	<3.0	<2.0	E.18
ASP	unsealed asphalt	8/12/2003	.16	<2.4	<1.8	<2.0	<1.9	<1.7	<1.3	<2.7	<2.4	<2.0	<3.0	<2.0	E.08
ASP	unsealed asphalt	8/21/2003	.34	<2.4	<1.8	<2.0	<1.9	<1.7	<1.3	<2.7	E.05	<2.0	<3.0	<2.0	E.14
ASP	unsealed asphalt	9/26/2003	.17	<2.4	<1.8	<2.0	<1.9	<1.7	<1.3	<2.7	E.05	<2.0	<3.0	<2.0	E.05
Parking lots in use															
CNR	coal-tar-emulsion-sealed	9/30/2003	12	E.15	E.04	E.85	<1.9	<1.7	<1.3	<2.7	4.2	E.24	<3.0	<2.0	4.6
LBJ	coal-tar-emulsion-sealed	9/28/2003	5.4	<2.4	E.03	E.29	E.06	<1.7	<1.3	E.12	E.20	E.09	<3.0	<2.0	E1.1
OSL	coal-tar-emulsion-sealed	9/30/2003	2.3	E.05	<1.8	E.16	<1.9	<1.7	<1.3	E.04	E1.1	E.04	<3.0	<2.0	
UNP	coal-tar-emulsion-sealed	9/30/2003	16	<2.4	<1.8	E.79	<1.9	<1.7	<1.3	<2.7	8.7	E.10	<3.0	<2.0	3.6
UTN	coal-tar-emulsion-sealed	9/28/2003	7.1	<2.4	<1.8	.53	E.30	<1.7	<1.3	E.41	2.9	E.01	<3.0	<2.0	E1.1
SOC	asphalt-emulsion-sealed	9/28/2003	5.1	<2.4	<1.8	.42	E.09	<1.7	<1.3	E.09	E1.7	<2.0	<3.0	<2.0	E1.8
ZLK	unsealed asphalt	9/30/2003	.24	<2.4	<1.8	<2.0	<1.9	<1.7	<1.3	<2.7	E.09	<2.0	<3.0	<2.0	E.05

Table 4. Particulate-phase concentrations of major and trace elements in washoff samples from parking lots, Austin, Texas, 2003.

[In milligrams per kilogram. Isa, insufficient sediment mass for analysis; --, not analyzed; Note: Data analyzed by custom method and therefore not available in USGS database.]

Site name	Type of surface	Date	Aluminum	Calcium	Iron	Potassium	Magnesium	Sodium
Test plots								
MON	coal-tar emulsion-sealed	8/21/2003	45,000	156,000	20,200	7,320	5,070	990
TAR	coal-tar emulsion-sealed	8/21/2003	16,400	23,000	8,720	3,600	8,760	1,310
PAV	asphalt-emulsion-sealed	8/21/2003	20,000	110,000	12,500	6,710	51,100	2,510
ASP	unsealed asphalt	8/21/2003	14,800	29,200	7,840	3,470	10,500	1,180
MON	coal-tar emulsion-sealed	9/9/2003	23,900	39,500	9,400	4,430	13,700	1,450
TAR	coal-tar emulsion-sealed	9/9/2003	22,900	26,700	9,300	3,960	8,300	1,360
PAV	asphalt-emulsion-sealed	9/9/2003	80,300	5,870	11,500	3,980	2,930	727
ASP	unsealed asphalt	9/9/2003	Isa	Isa	Isa	Isa	Isa	Isa
MON	coal-tar emulsion-sealed	9/26/2003	79,900	21,800	12,000	4,520	9,440	907
TAR	coal-tar emulsion-sealed	9/26/2003	122,000	5,360	13,000	3,840	2,790	532
PAV	asphalt-emulsion-sealed	9/26/2003	19,700	50,600	4,300	4,570	23,800	1,250
ASP	unsealed asphalt	9/26/2003	12,600	102,000	5,200	6,340	42,200	1,930
Parking lots in use								
TCQ	coal-tar emulsion-sealed	9/7/2003	24,500	73,300	12,600	6,710	10,800	2,660
SSE	asphalt-emulsion-sealed	9/7/2003	26,800	13,400	6,040	2,330	4,030	610
WWB	asphalt-emulsion-sealed	9/7/2003	23,600	11,600	4,940	1,700	2,570	325
WWB replicate	asphalt-emulsion-sealed	9/7/2003	21,700	9,130	4,210	1,950	1,890	417
WWB replicate	asphalt-emulsion-sealed	9/7/2003	23,400	11,500	4,890	1,670	2,470	312
LAC	unsealed concrete	9/8/2003	18,000	147,000	14,200	6,080	15,300	3,500
LOW	unsealed concrete	9/8/2003	18,200	123,000	14,200	5,670	10,900	2,080
NWR	unsealed asphalt	9/8/2003	11,000	172,000	7,470	3,310	18,800	1,320
LBJ	coal-tar emulsion-sealed	9/28/2003	25,000	66,000	13,000	4,400	7,980	1,390
UTN	coal-tar emulsion-sealed	9/28/2003	27,000	86,300	12,000	4,560	7,770	1,510
SOC	asphalt-emulsion-sealed	9/28/2003	35,700	41,600	12,000	4,860	6,140	1,480
SOC replicate	asphalt-emulsion-sealed	9/28/2003	35,500	41,000	12,000	4,920	5,910	1,400
SOC replicate	asphalt-emulsion-sealed	9/28/2003	34,100	39,800	12,000	4,740	5,890	1,440
CNR	coal-tar emulsion-sealed	9/30/2003	27,000	32,800	9,300	3,710	6,950	1,020
OSL	coal-tar emulsion-sealed	9/30/2003	8,670	11,400	2,800	1,480	1,620	585
UNF	coal-tar emulsion-sealed	9/30/2003	23,400	54,600	11,000	4,100	5,540	1,480
ZLK	unsealed asphalt	9/30/2003	15,600	187,000	8,000	6,160	16,600	2,620
ZLK replicate	unsealed asphalt	9/30/2003	15,200	192,000	8,200	6,010	16,200	2,690

Table 4. Particulate-phase concentrations of major and trace elements in washoff samples from parking lots, Austin, Texas, 2003—Continued

Site name	Barium	Beryllium	Cadmium	Cobalt	Chromium	Copper	Mercury	Lithium	Manganese	Nickel	Lead	Selenium
Test plots												
MON	187	1.4	3.51	6.2	91.6	34.8	0.08	30.5	238	26.7	85.6	7.4
TAR	154	.5	5.16	2.6	46.0	61.4	Isa	8.0	88.9	21.1	89.8	2.1
PAV	255	.6	2.04	4.4	79.1	147	Isa	10.0	221	32.5	220	3.2
ASP	145	.6	1.24	2.8	36.4	46.5	.04	7.6	104	15.6	98.9	2.7
MON	157	.6	.86	3.1	53.2	52.2	Isa	12.5	137	13.0	114	3.2
TAR	195	.6	.64	3.0	49.6	49.0	Isa	13.4	127	13.9	82.8	3.2
PAV	189	.8	.17	2.5	73.9	28.5	.08	33.9	52.9	16.1	44.7	11.1
ASP	Isa	Isa	Isa	Isa	Isa	Isa	Isa	Isa	Isa	Isa	Isa	Isa
MON	176	.9	1.50	4.2	121	57.9	Isa	33.0	112	21.1	228	8.1
TAR	164	1.2	.22	2.7	128	25.3	.10	50.8	40.2	17.5	96.9	14.2
PAV	117	.5	.57	2.0	36.3	29.7	.13	7.4	111	10.9	78.3	2.2
ASP	162	.4	.88	2.0	85.3	33.5	Isa	4.4	111	8.8	246	1.7
Parking lots in use												
TCQ	264	.7	1.87	4.1	92.8	69.0	.08	13.7	206	20.9	268	4.1
SSE	131	.4	.49	2.8	51.1	23.8	.05	14.1	64.9	15.7	119	3.2
WWB	160	.4	.41	1.5	31.8	34.6	.02	12.0	36.8	12.6	35.4	3.1
WWB replicate	127	.3	.36	1.0	26.6	19.1	—	11.1	28.9	10.6	27.1	2.7
WWB replicate	160	.3	.40	1.5	31.4	33.8	—	11.6	37.0	12.5	34.8	3.1
LAC	536	.7	.81	6.0	164	124	.24	8.7	252	55.3	321	2.1
LOW	246	.6	.68	11.9	385	78.8	.05	11.3	400	35.1	577	—
NWR	152	.3	.60	2.8	38.4	48.3	.03	6.9	151	26.4	75.9	—
LBJ	439	.7	2.10	6.0	90.5	143	.18	12.4	188	22.4	223	4.1
UTN	257	.6	1.90	5.3	78.1	71.9	.26	12.1	166	17.6	174	4.2
SOC	268	.7	.87	3.7	68.8	76.2	.09	15.8	132	22.9	115	5.7
SOC replicate	274	.7	.88	3.8	62.7	79.9	—	15.8	129	22.0	116	4.1
SOC replicate	269	.7	.89	3.7	65.9	74.0	—	15.6	129	22.4	116	4.1
CNR	199	.5	1.80	4.2	45.1	46.0	.09	12.7	123	15.3	74.1	3.1
OSL	59.8	.2	.33	1.1	40.4	24.5	.05	3.7	43.7	4.3	135	1.2
UNF	174	.5	1.20	9.1	108	65.6	.07	10.1	153	49.2	74.3	3.2
ZLK	184	.6	.41	2.7	24.8	26.9	.05	6.8	213	7.7	37.2	2.1
ZLK replicate	178	.5	.38	2.7	77.9	29.8	.04	6.4	221	12.6	34.6	2.1